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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

FLIGHT TESTS OF TWO AIRPLANES HAVING MODERATELY HIGH

EFFECTIVE DIHEDRAL AND DIFFERENT DIRECTIONAL

STABILITY AND CONTROL CHARACTERISTICS

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NACA

WASHINGTON

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SUMMARY

Flight tests of a twin-engine midwing attack bomber and a single-engine low-wing fighter airplane showed both airplanes to have moderately high effective dihedral but different directional stability and control character-istics.

The attack bomber had a high degree of directional stability and the variation of rudder force required for trim with speed was small. The fighter had considerably less directional stability than the attack bomber and the rudder forces required for trim as the speed and engine power were varied were relatively high. In flying the attack bomber, pilots did not observe any unusual or undesirable lateral control characteristics. On the other hand pilots reported control coordination was difficult with the fighter when changing speed or power, with the result that inadvertent sideslipping occurred. When this motion occurred the airplane tended to roll and the pilot was required to apply aileron forces con-tinually. Pilots also considered the rough-air control characteristics objectionable because of the aileron forces that were required when inadvertent sideslipping occurred. When the rudder forces were reduced with a spring-tab rudder, pilots noted a marked improvement in the lateral and directional control characteristics.

INTRODUCTION

In the course of flight tests made at the Langley Laboratory of the NACA to determine the flying qualities of an attack bomber and a fighter airplane, both airplanes

were found to have moderately high effective dihedral at
moderate and high speeds but different directional sta-
bility and control characteristics. Unpublished tests
in which high effective dihedral was found to be objec-
tionable have been reported at the Ames Laboratory of
the NACA. The present report gives a discussion of the
effects of differences in the directional stability and
control characteristics on the lateral control charac-
teristics of a fighter and an attack bomber having
approximately the same moderately high effective dihedral.
The fighter airplane was tested with both the standard
rudder and an experimental spring-tab rudder.

TEST RESULTS AND DISCUSSION

Figures 1 and 2 are three-view drawings of the two
airplanes that were tested. Pertinent dimensions are
given in the figures.

The effective dihedral was calculated from flight
measurements of the variation of aileron angle with side-
slip angle in steady sideslips and the variation of helix
angle $pb/2V$ with aileron deflection in rudder-fixed
aileron rolls. The effective-dihedral angle in degrees
is given by the formula

$$\Gamma_e = (57.3)^2 \frac{C_{l_p}\left(\dfrac{d\frac{pb}{2V}}{d\delta_a}\right)\left(\dfrac{d\delta_a}{d\beta}\right)}{\dfrac{C_{l_\beta}}{\Gamma}}$$

where

Γ_e effective-dihedral angle, degrees

C_{l_p} variation of rolling-moment coefficient C_l
            with helix angle $pb/2V$ in radians (obtained
            from reference 1)

$\dfrac{d\frac{pb}{2V}}{d\delta_a}$ variation of helix angle $pb/2V$ in radians with
            aileron angle δ_a in degrees (obtained from
            rudder-fixed aileron rolls in flight)

$d\delta_a/d\beta$ · variation of aileron angle δ_a in degrees with sideslip angle β in degrees (obtained from steady sideslips in flight)

C_{l_β}/Γ variation of rolling-moment coefficient C_l with sideslip angle β in radians per unit dihedral angle Γ in radians (obtained from reference 1)

In the rated-power clean condition at an indicated airspeed of 250 miles per hour, the effective dihedral was calculated to be 5.6° for the attack bomber and 5.4° for the fighter.

An indication of the degree of directional stability of the two airplanes is shown in figures 3 and 4 by the maximum change in sideslip angle due to abrupt full aileron deflection. These figures are time histories of rudder-fixed full-aileron rolls out of turns. These maneuvers were started at a lift coefficient of 1.35 for the fighter and 1.13 for the attack bomber. The maximum value of helix angle $pb/2V$ reached was 0.062 radian for both airplanes. Figures 3 and 4 show that the attack bomber had considerably more directional stability than the fighter; the maximum change in sideslip angle was 12° for the attack bomber and 21° for the fighter.

Figures 5 and 6 give the steady sideslip characteristics of the two airplanes. The curves of rudder angle and rudder force plotted against sideslip angle in these figures are also a measure of the directional stability of the airplanes. Inspection of the rudder-angle curves shows the greater directional stability of the attack bomber that was pointed out previously. The data for the fighter show a further decrease in directional stability at small sideslip angles, especially in left sideslips. The decrease in directional stability at small sideslip angles was even more apparent in flight at lower speeds.

In flying the fighter airplane, pilots reported that control coordination was difficult during changes in speed and power and that use of the controls to maintain steady flight in rough air resulted in objectionable rolling motions. Because of the relatively large variation of rudder trim force with speed and power with this airplane, pilots experienced difficulty in maintaining zero or negligible sideslip angles when the speed or power was changed. When appreciable sideslip angles developed, the airplane tended to roll and the pilot was required to

apply aileron forces continually to overcome the rolling
moment due to sideslip. Because of the low directional
stability, pilots also considered the lateral control
characteristics unsatisfactory when flying at constant
speed. In this case inadvertent sideslipping caused the
objectionable tendency of the airplane to roll. When
flying in rough air, if a gust caused the initial motion,
pilots reported that it was especially difficult to
return the airplane to steady flight.

In flying the attack bomber, pilots did not observe
any unusual or undesirable lateral control characteristics.
With the high directional stability and the small vari-
ation of rudder trim force with speed, the airplane was
not as likely to reach angles of sideslip sufficient to
cause rolling.

The effect of reducing the rudder forces of the
fighter was investigated by equipping the airplane with
an experimental spring-tab rudder. Figure 7 shows a com-
parison of the variation of rudder angle and rudder force
with sideslip angle in steady sideslips for this airplane
when equipped with the original rudder and the spring-tab
rudder. With the spring-tab rudder the rudder force
required to produce a given sideslip angle and the rudder
forces required for trim were considerably reduced.
Pilots noted that with the lighter rudder forces it was
easier to maintain negligible sideslip angles and the
lateral control characteristics were improved. The fact
that improved lateral control characteristics resulted
when the rudder forces were reduced is not consistent
with various requirements based on the relation between
rudder forces and the rolling response that have been
proposed to set an upper limit on the allowable effective
dihedral. For example, a tentative requirement has been
proposed at the Ames laboratory which states that the
angle of bank reached in 2 seconds should be less than
0.0035 or 0.0040 radian per pound of rudder force. From
aileron-fixed rudder kicks made at 200 miles per hour in
the clean, power-on condition, the angle of bank reached
in 2 seconds was found to be 0.0026 radian per pound of
rudder force for the attack bomber and 0.0048 radian per
pound of rudder force for the fighter with the original
rudder. The angle of bank that would be reached in
2 seconds with the fighter equipped with the spring-tab
rudder was estimated to be 0.0082 radian per pound of
rudder force at 200 miles per hour. Since the spring tab
becomes more effective as the speed is increased, the

difference between the angles of bank reached in 2 seconds
per pound of rudder force with the original rudder and the
spring-tab rudder will be even greater at higher speeds.
The data show that the attack bomber satisfied the proposed
requirement and that the fighter with either the original
rudder or the spring-tab rudder did not satisfy the
proposed requirement. The fighter with the original
rudder came much closer to satisfying the requirement than
the same airplane with the spring-tab rudder, but the
lateral control characteristics were better with the
spring-tab rudder. A criterion for the upper limit of
effective dihedral based on the angle of bank reached in
2 seconds with a given rudder force therefore appears
unsatisfactory and such a criterion should take into
account other factors such as the directional stability
of the airplane.

The use of high effective dihedral in conjunction
with light rudder forces has been suggested as a means of
increasing the rolling performance of an airplane. Fig-
ures 8 and 9 show that considerable rolling velocity can
be obtained by use of the rudder with both airplanes, but
these figures also show that there is an appreciable time
lag between application of the rudder and the resultant
rolling motion. For this reason, pilots considered this
means of obtaining a high rolling velocity to be unsatis-
factory.

CONCLUSIONS

Flight tests of two airplanes, a fighter airplane
and an attack bomber, which had different directional
stability and control characteristics and approximately
the same moderately high effective dihedral, led to the
following conclusions concerning the effects of the
different directional stability and control character-
istics on the flying qualities of the two airplanes:

With the fighter, which had low directional stability
and a large variation of rudder trim force with speed and
power, pilots reported control coordination was difficult
when changing speed or power, with the result that
inadvertent sideslipping occurred. When this motion
occurred, the airplane tended to roll and the pilot was
required to apply aileron forces continually. Pilots
also considered the rough-air control characteristics

objectionable because of the aileron forces that were
required when inadvertent sideslipping occurred. When
the rudder forces were reduced with a spring-tab rudder,
pilots noted a marked improvement in the lateral and
directional control characteristics.

With the high degree of directional stability and
low directional trim forces of the attack bomber, pilots
observed no unusual or undesirable lateral control
characteristics.

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REFERENCE

1. Pearson, Henry A., and Jones, Robert T.: Theoretical
        Stability and Control Characteristics of Wings
        with Various Amounts of Taper and Twist. NACA Rep.
        No. 635, 1938.
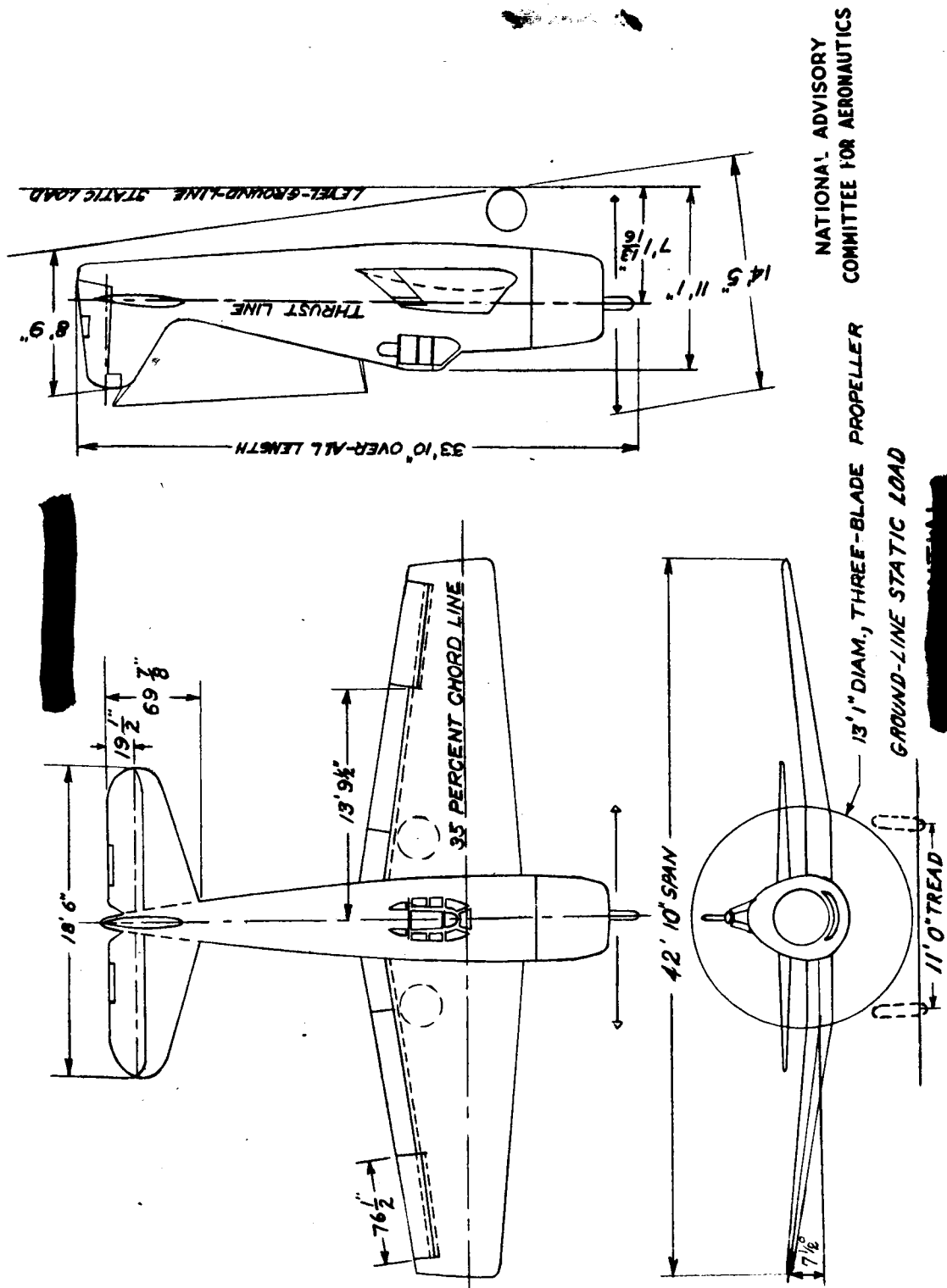
Figure 1.- Three-view drawing of fighter airplane tested.

Fig. 2   NACA CB No. L5H08
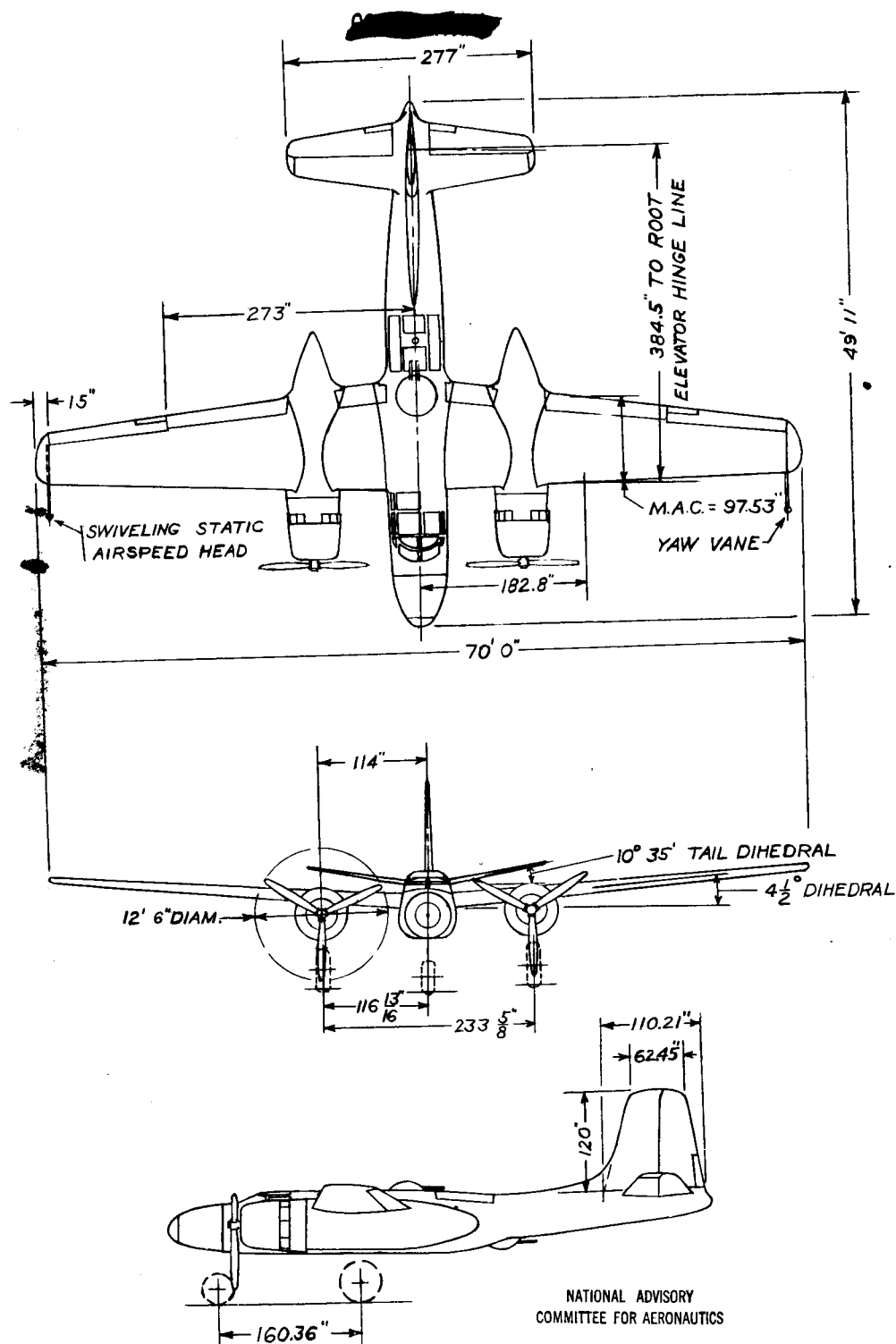
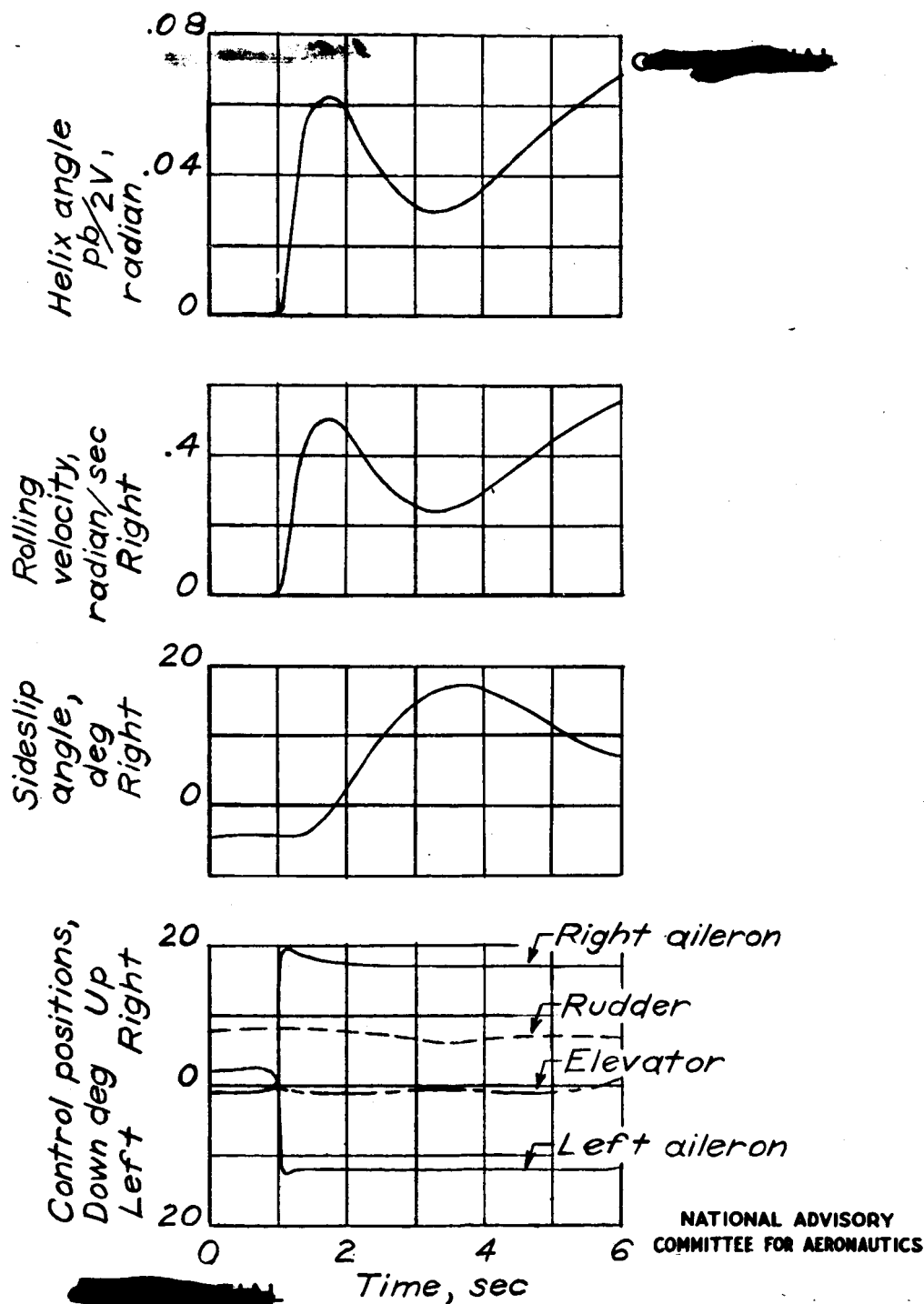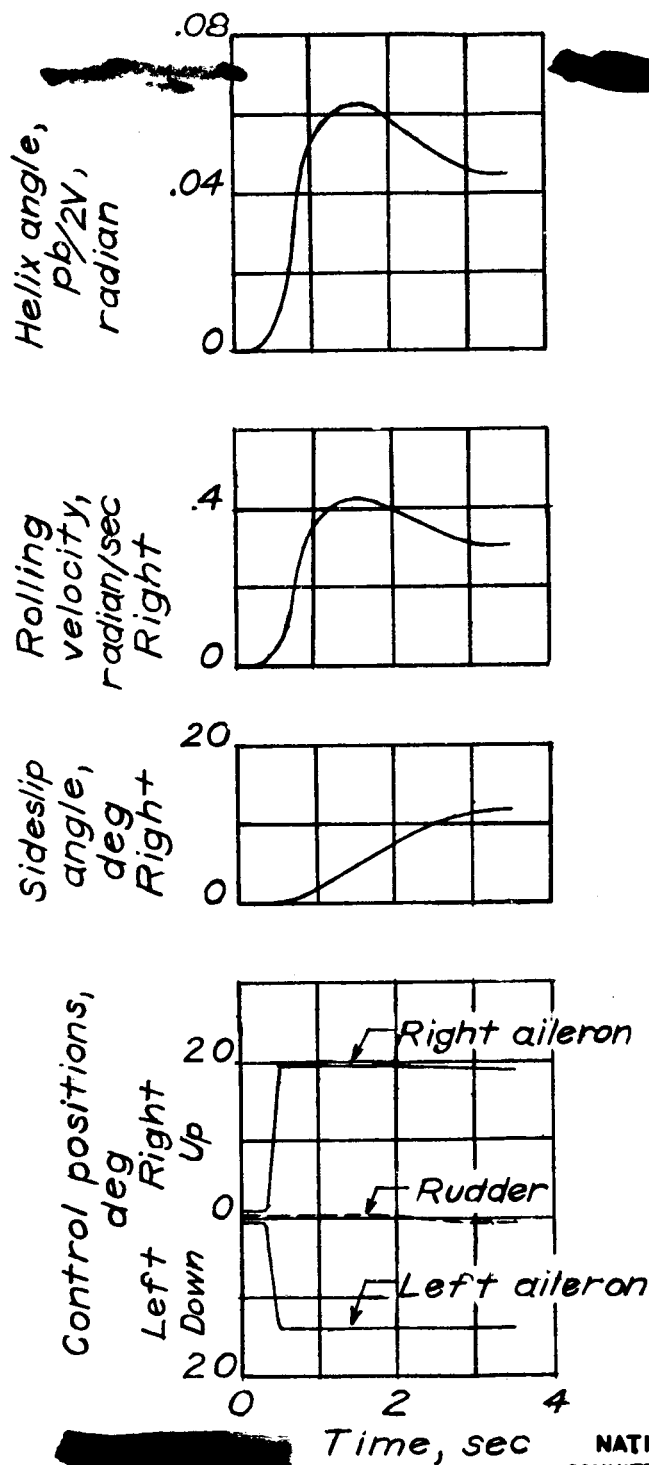

Figure 2.- Three-view drawing of attack bomber tested.

Figure 3.- Time history of a full-deflection aileron roll out of a
left turn with rudder held fixed for fighter airplane.
Clean condition; power for level flight; indicated air-
speed, $V_i = 104$ miles per hour; lift coefficient,
$C_L = 1.35$ at start of maneuver.

Fig. 4   NACA CB No. L5H08

Figure 4.- Time history of a full-deflection aileron roll out of a
left turn with rudder held fixed for attack bomber.
Clean condition; power for level flight; indicated
airspeed, V_i = 145 miles per hour; lift coefficient,
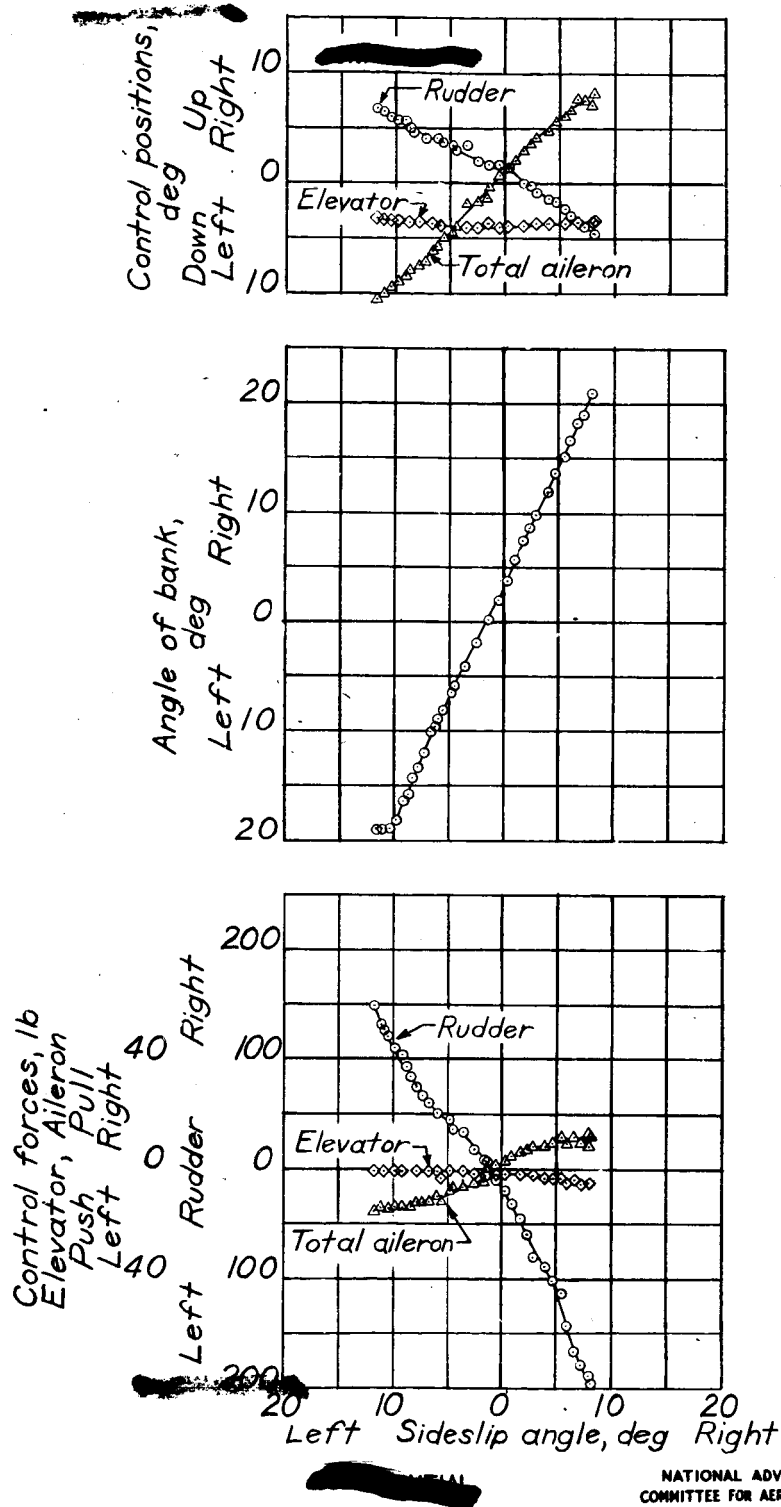C_L = 1.13 (approx.) at start of maneuver.

Figure 5.- Steady sideslip characteristics for fighter airplane. Clean condition; rated power; indicated airspeed, V_i = 252 miles per hour.

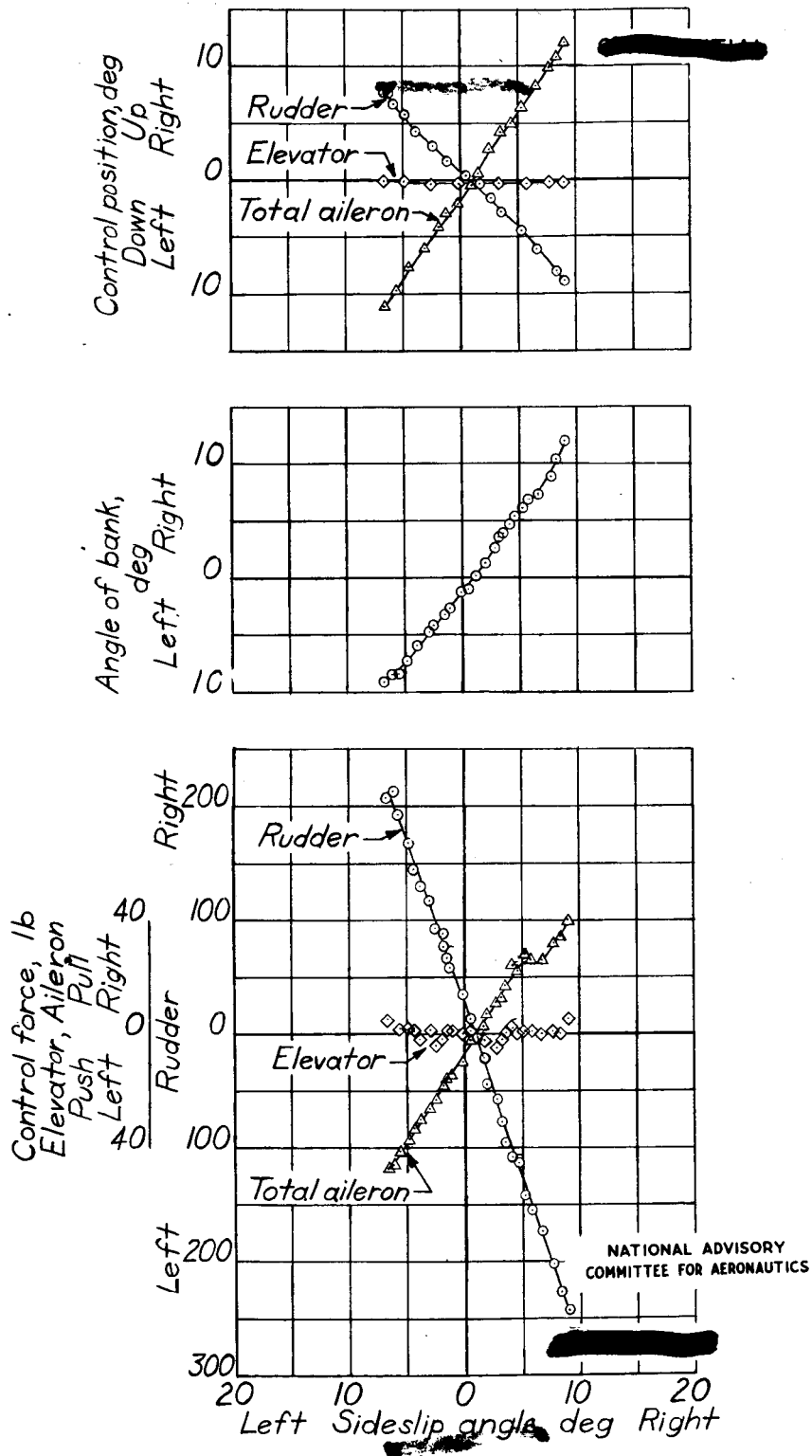Fig. 6   NACA CB No. L5H08

Figure 6.- Steady sideslip characteristics for attack bomber. Clean condition; rated power; indicated airspeed, V_i = 252 miles per hour.
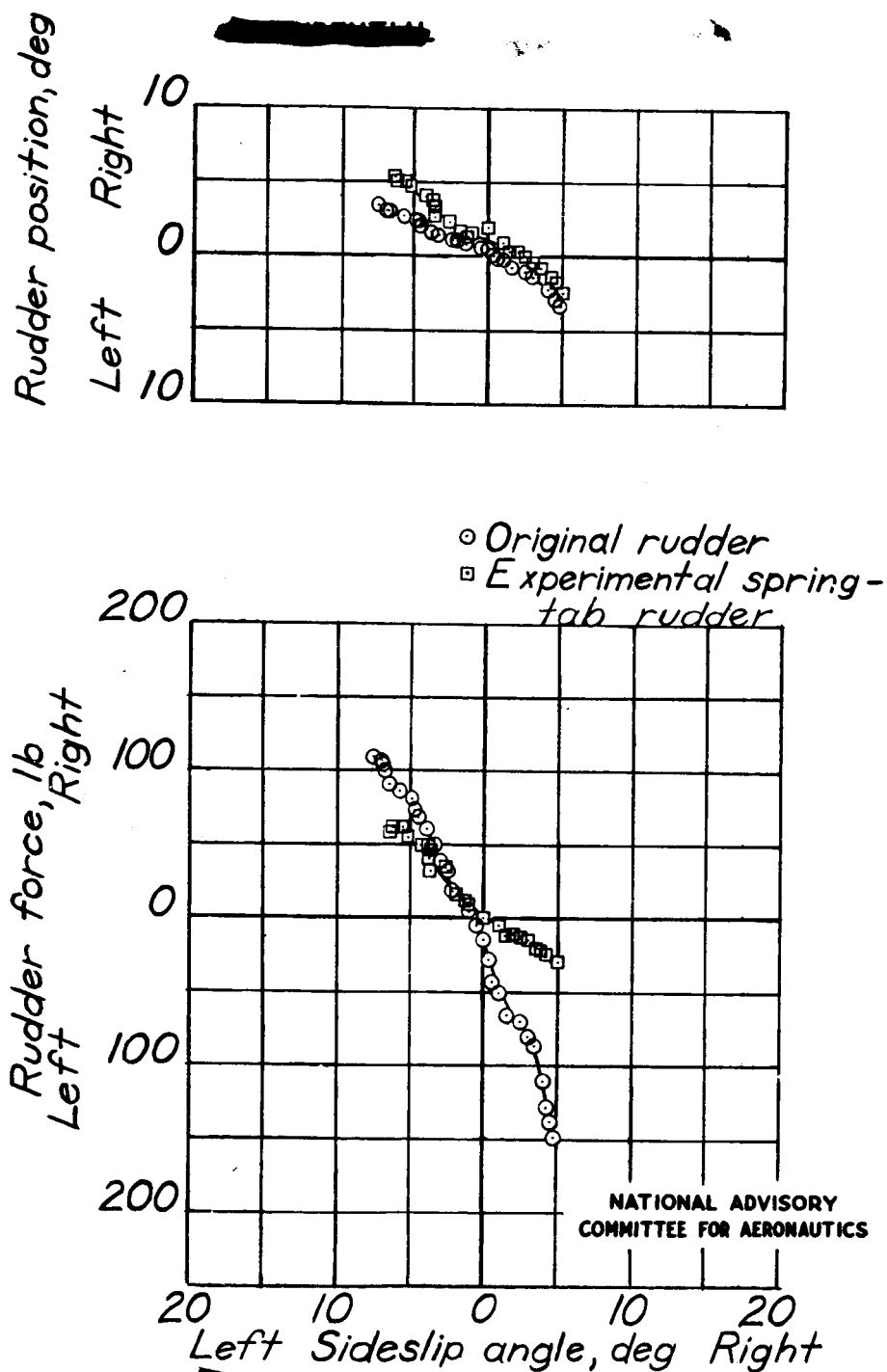
Figure 7.- Variation of rudder angle and rudder force with
           sideslip angle for fighter airplane with original
           rudder and experimental spring-tab rudder with
           5-pound preload. Clean condition; rated power;
           indicated airspeed, V_i = 300 miles per hour.

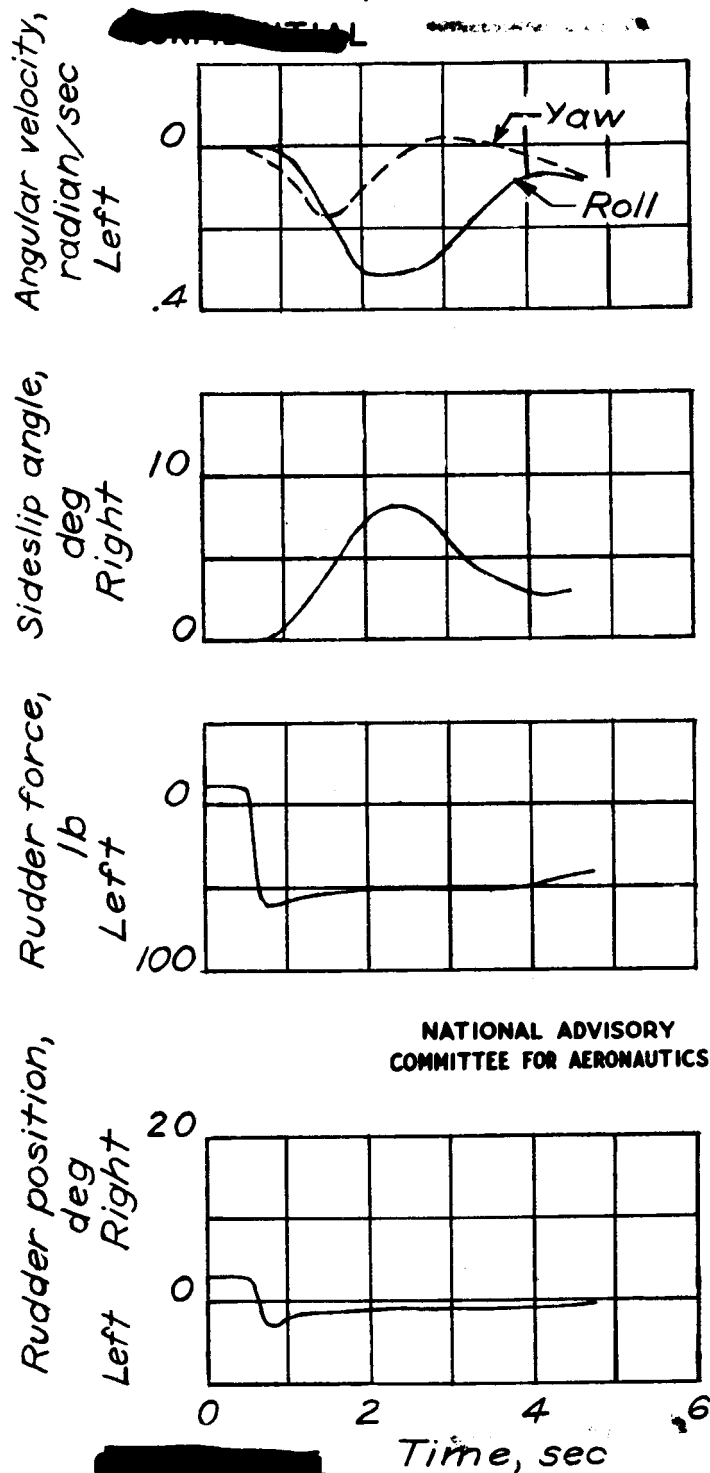Fig. 8   NACA CB No. L5H08

Figure 8.- Time history of a rudder kick with ailerons held fixed for fighter airplane. Clean condition; level-flight power; indicated airspeed, $V_i = 197$ miles per hour.
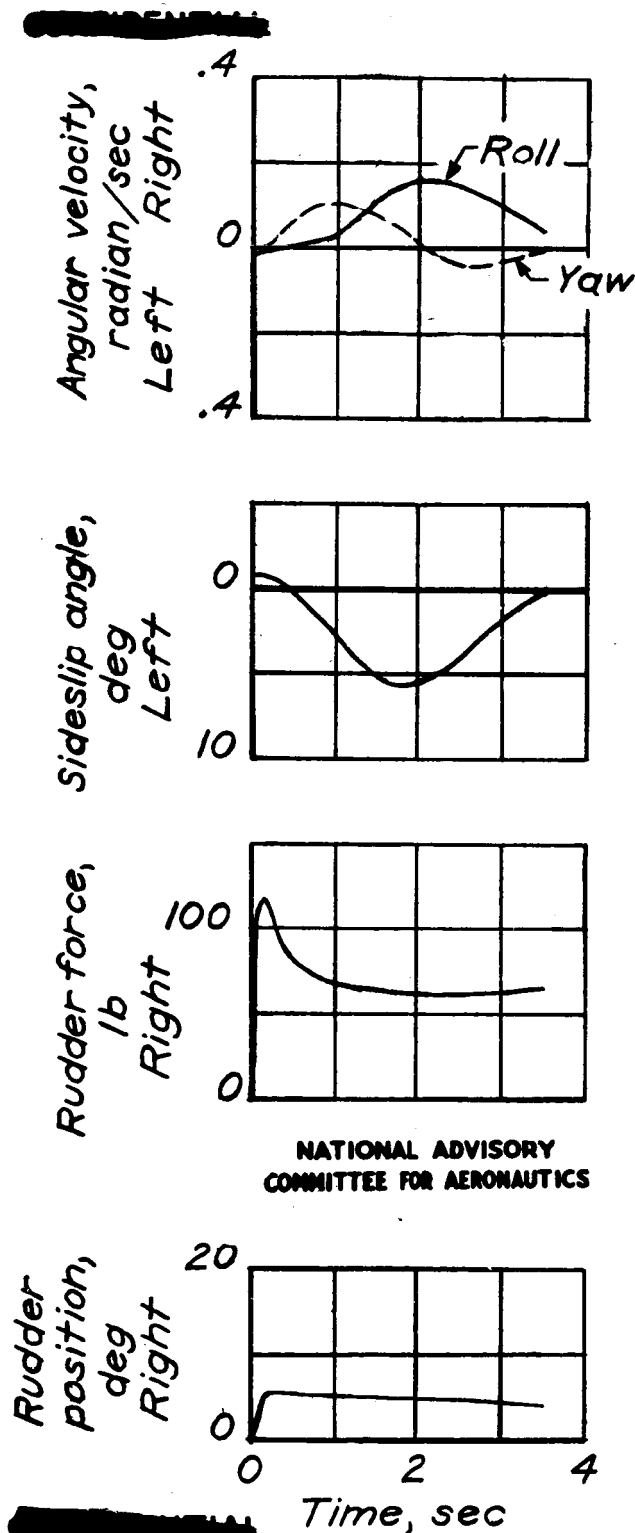
Figure 9.- Time history of a rudder kick with ailerons held
        fixed for attack bomber. Clean condition; rated
        power; indicated airspeed, V_1 = 200 miles per
        hour.